Fabrication of Ordered Cu_2O Quantum Dot Arrays on $SrTiO_3$ (100)

Name: Yingge Du

Affiliation: Department of Material Science and Engineering, University of Virginia

Co-authors: James F. Groves, Igor Lyubinetsky[1] and Thevuthasan, Suntharampillai[1]

[1] Pacific Northwest National Laboratory

Presentation Outline

- **Introduction**

  Why we are interested in $Cu_2O/SrTiO_3$.

  Why directed self-assembly using FIB.

- **Experiment**

  Experiment setup

  Experiment procedures

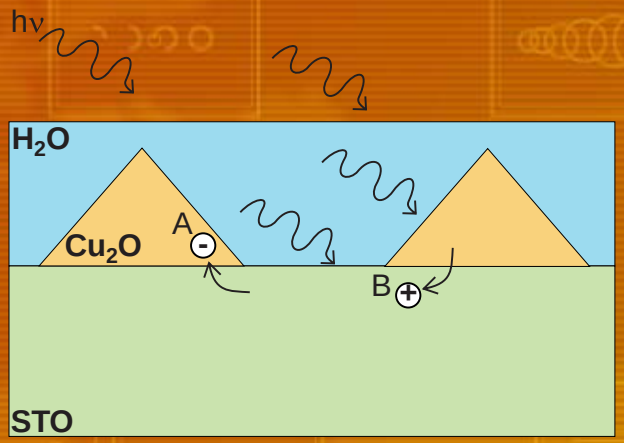
- **Results**

- **Discussions**

Introduction

Why we are interested in $Cu_2O/SrTiO_3$

- Photocatalytic decomposition of water on Cu_2O interface under visible light irradiation[1].
  - Produce hydrogen for fuel cells
  - High density QD array for maximum device efficiency



A: photo-oxidation (oxygen production)
B: photo-reduction (hydrogen production)

- Quantum dots – 0 D, size-dependent optical and electrical properties - new applications
  - Cu_2O QDs are expected to be exhibit spatially confined exciton states - good candidate to observe Bose-Einstein condensation

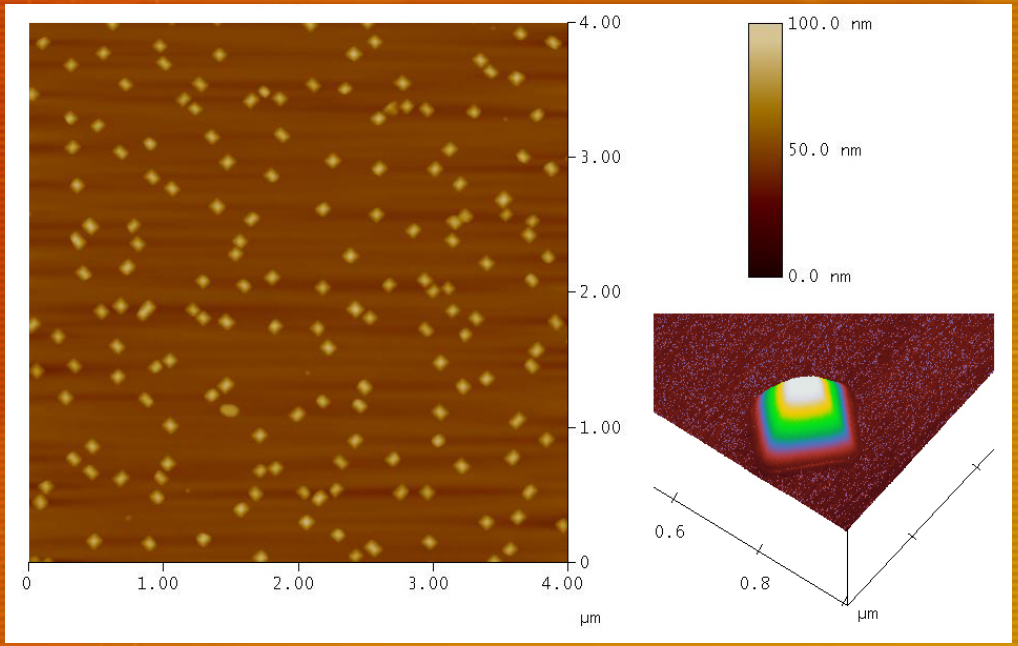
1. M. Hara, T. Kondo, M. Komoda, S. Ikeda, K. Shinohara, A. Tanaka, J. N. Kondo, and K. Domen, *Chem. Commun.* 357 (1998).

Introduction

Why we are interested in directed self-assembly of QDs.

- MBE growth of semiconductor QDs for V, III-V, II-VI.

  Oxygen plasma-assisted MBE growth of metal oxide QDs (e.g. $Cu_2O/SrTiO_3$)
  - Self-assemble on lattice mismatched strain system
  - Quasirandom on planar substrate.



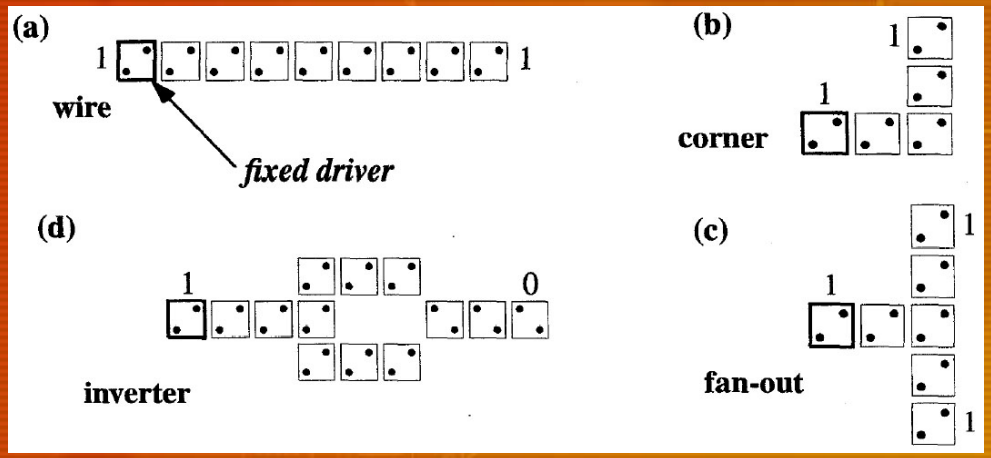
Introduction

Why we are interested in directed self-assembly of QDs.

- New nanodevices and new applications

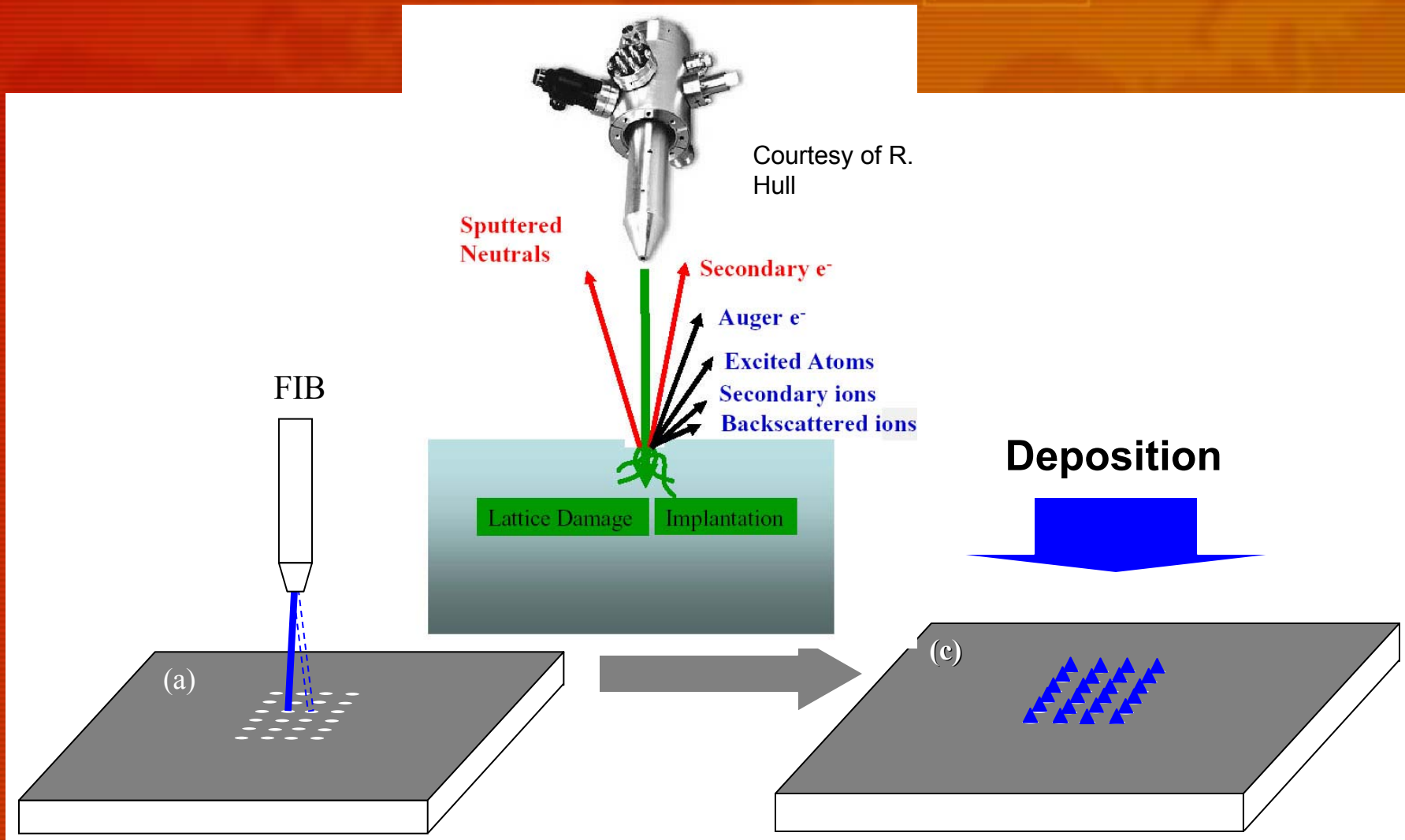
  Size and location control - reproducibility

  Ability to join the dots into complex assemblies creates many scientific opportunities.
  - Quantum cellular automata[2]
  - Quantum dot lasers

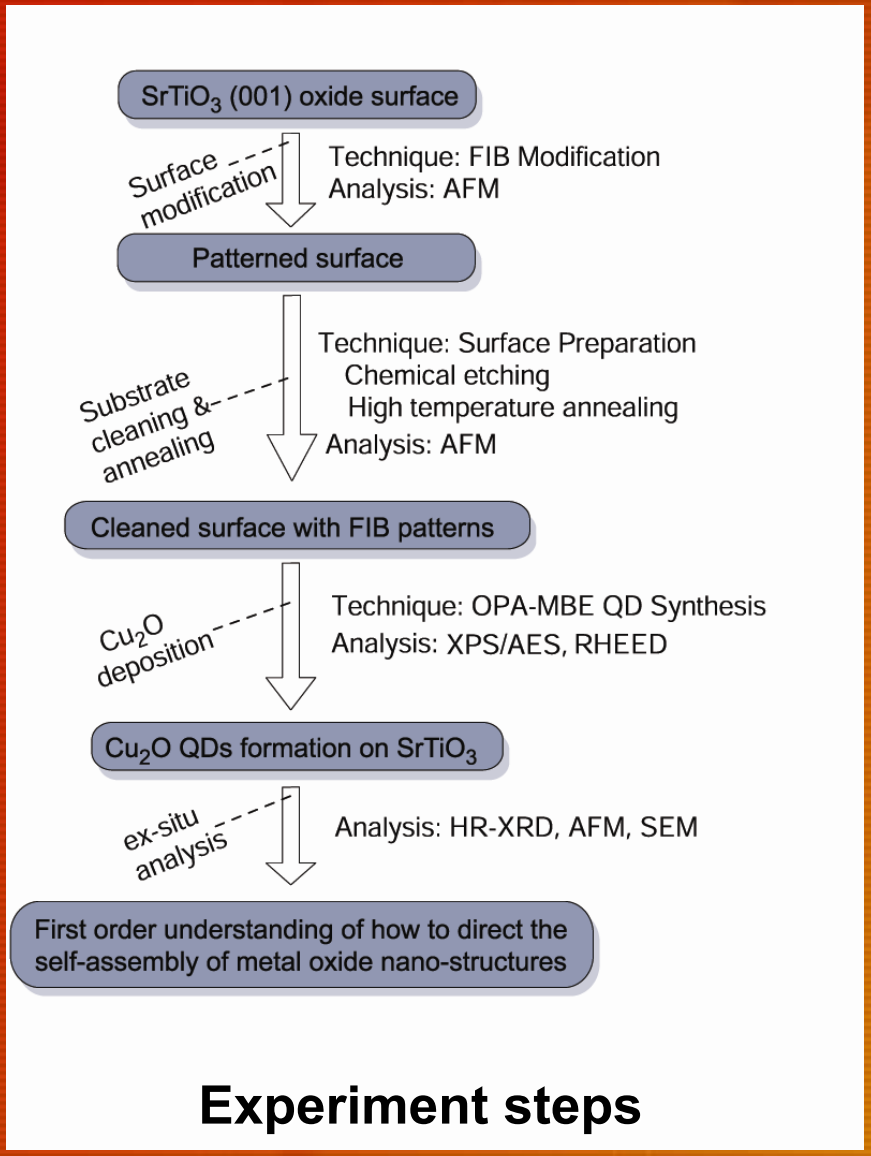


2. Porod, W. (1998). Cellular Neural Networks and Their Applications Proceedings, 1998 Fifth IEEE International Workshop, 20.

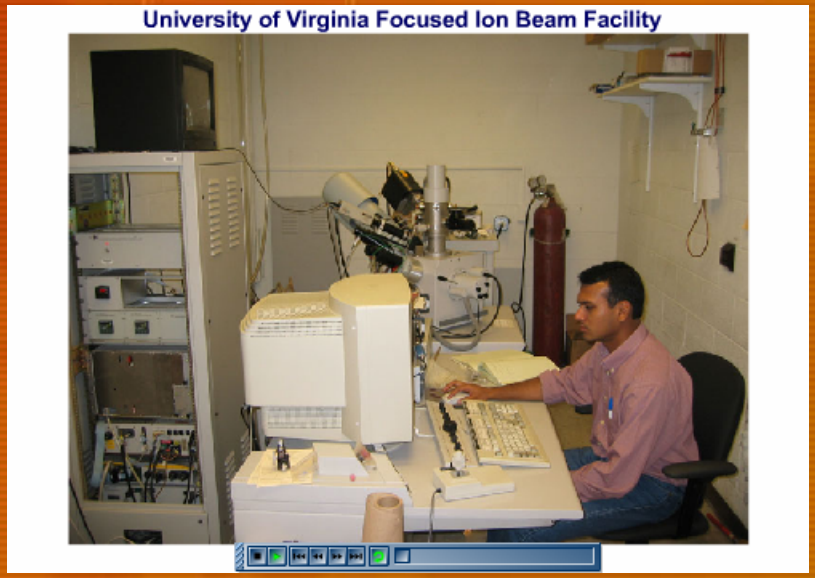
Experiment expectations

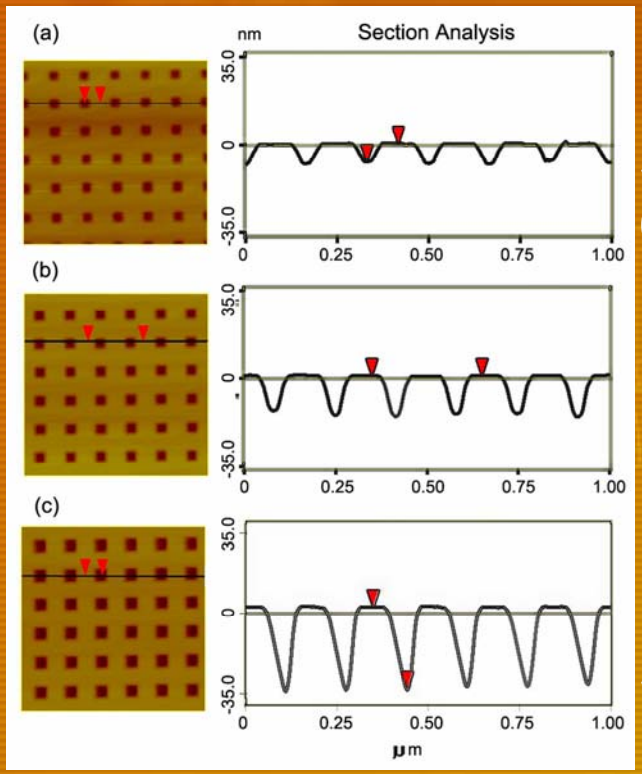


Experiment



Experiment steps



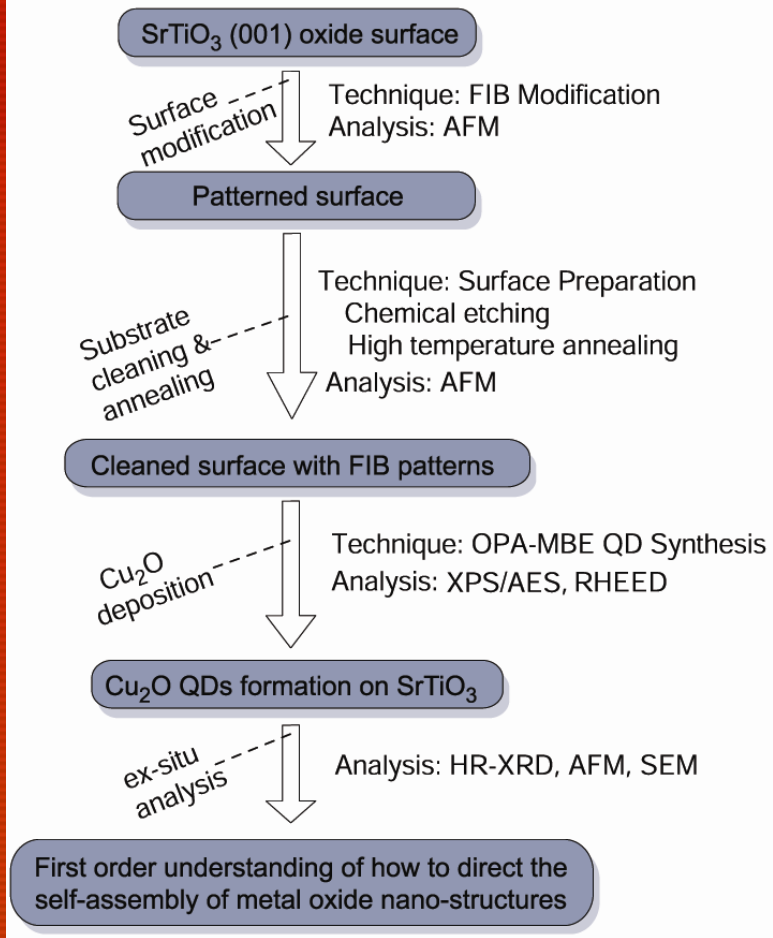


167 nm
5 scans
625x5

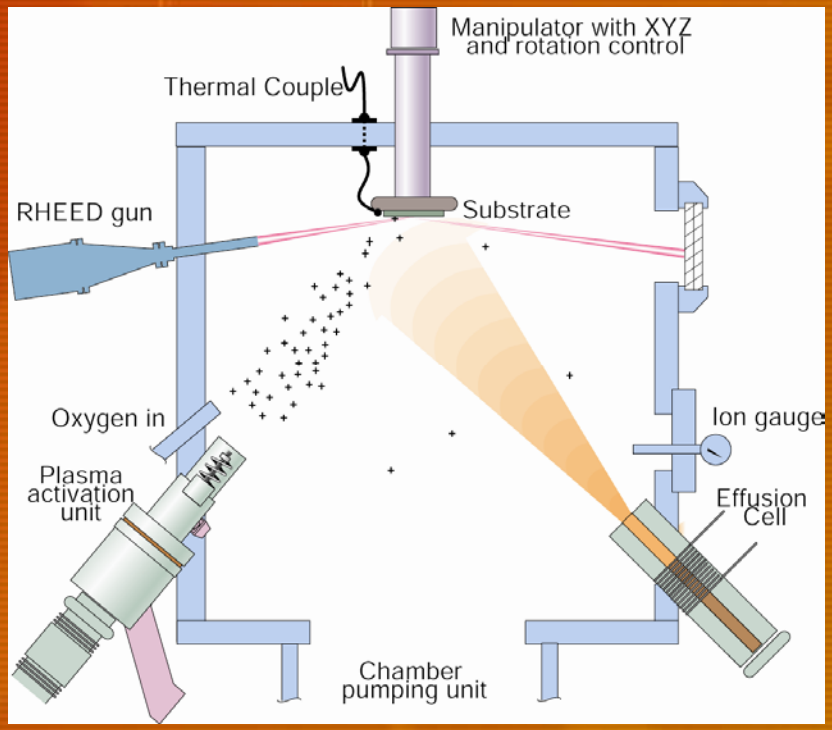
167nm
10,

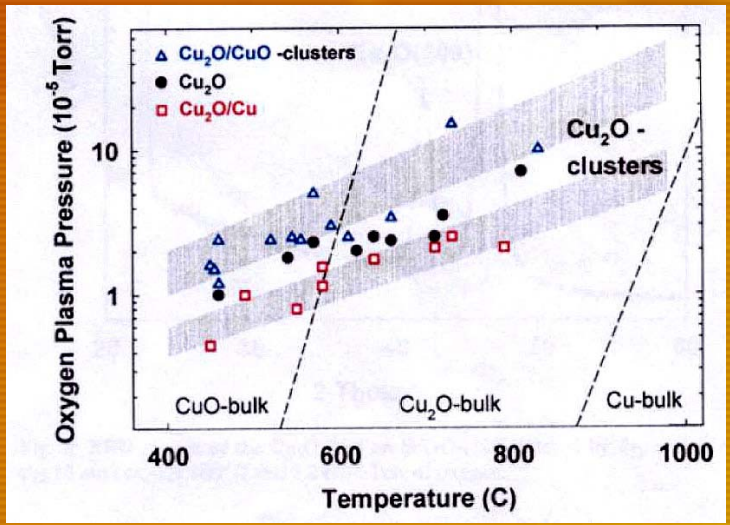
167nm
50

Experiment



Experiment steps

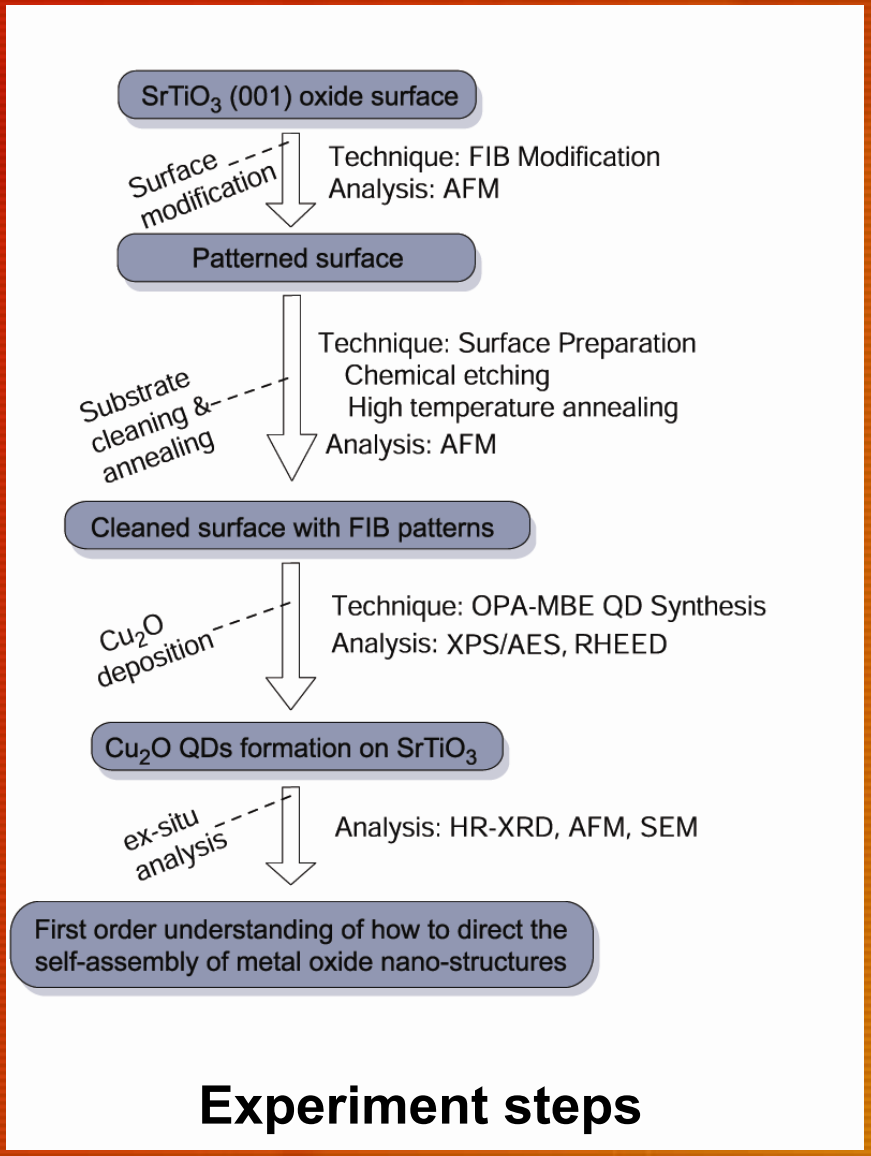




As determined by XPS & AES[3]

3. Lyubinetsky, I. et al., (2003). *J. Appl. Phys.*, 94, 7926.

Experiment



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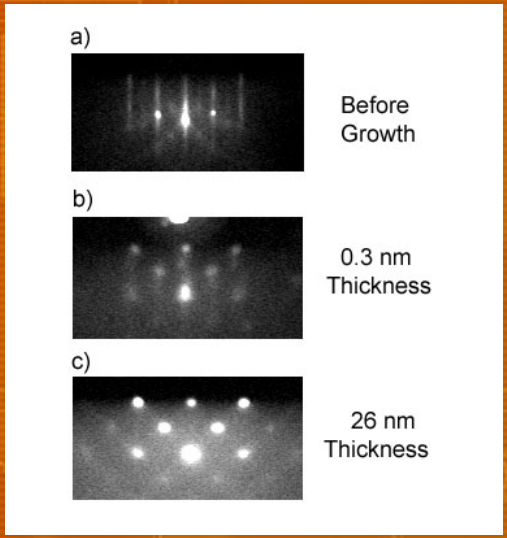
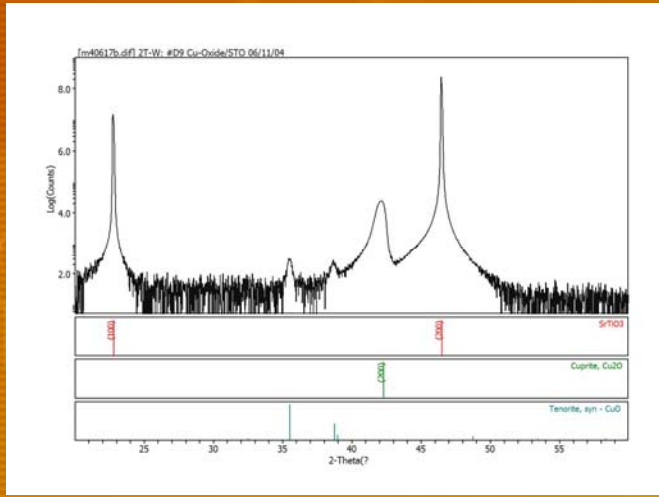


V-W growth
Without wetting



HRXRD – Epitaxial
Cu_2O (100) // $SrTiO_3$ (100)

Results:

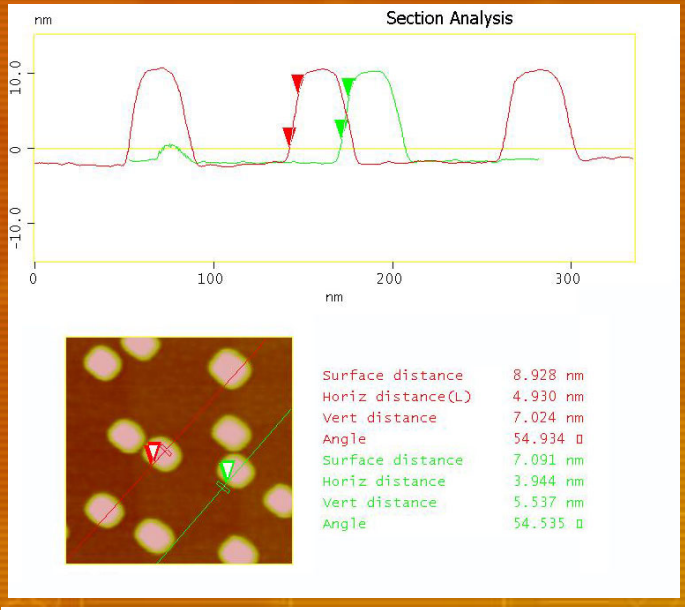
Non-patterned region (Flat $SrTiO_3$ surface)

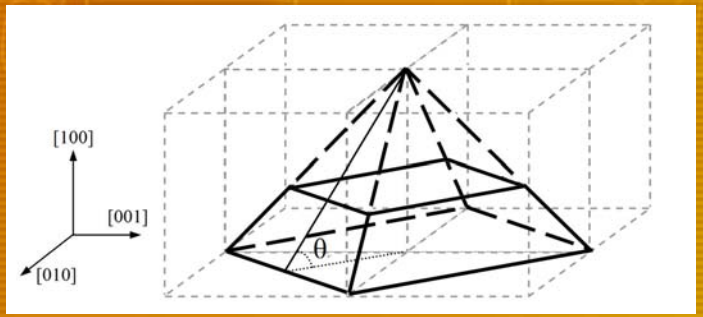
- Shape and size of Cu_2O QDs
  - Weak dependence on thickness init.
  - Truncated pyramidal crystals
  - {111} side walls with (100) flat tops

  Reproducible, stable, epitaxial

- Density of Cu_2O QDs
  - Strong dependence on T
  - Fixed T, close to linear with thickness before coalescence.

  To fit the pattern, need to adjust density





Results:

Patterned regions : Microscale

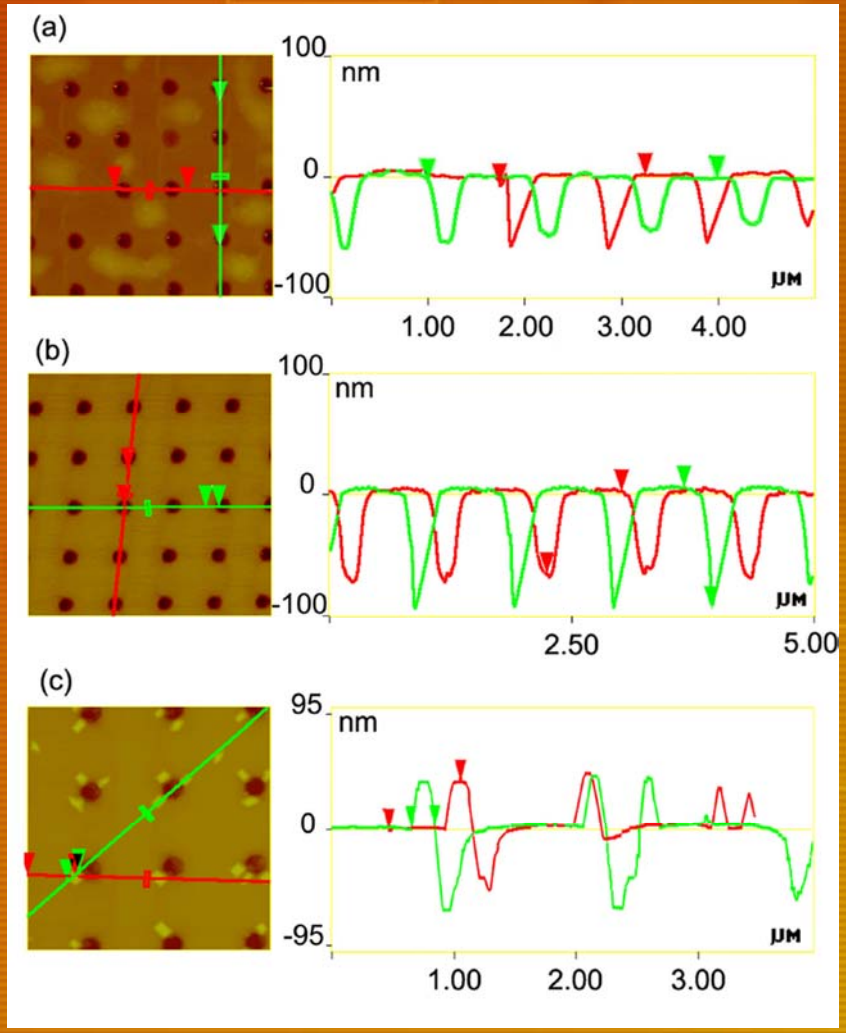
- **Best result**
  - One FIB pit – 1-4 nanodot.
  - no islands formed elsewhere

Process conditions:

1 um spacing

T = 725°C

Thickness: 7 Å



Ga ion density 5.6×10^{18} ions/cm^2

4.4×10^8 Ga ions on each dot

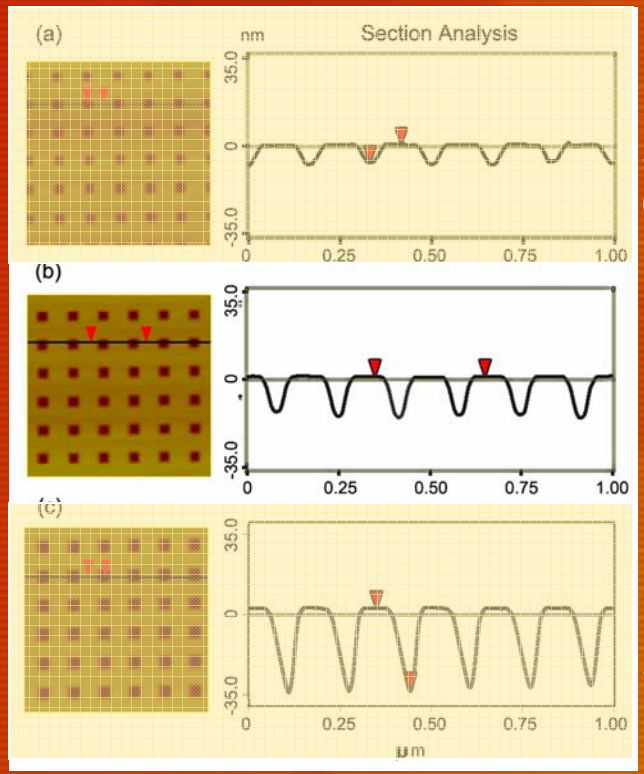
Directions:

1. Reproducibility
2. Higher integration
3. Less surface damage

Results:

Patterned regions : Nanoscale

- **Best result**
  - One FIB pit – one nanodot.
  - Few islands formed elsewhere
  - Larger size, lower height



167 nm
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10,

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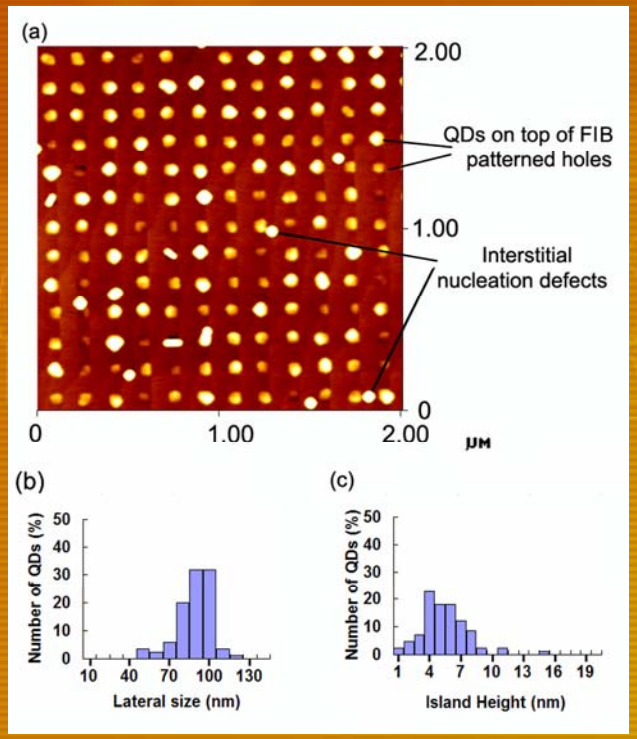
Process conditions:

b) region

T = 700°C

Thickness: 7 Å



Results:

Process conditions:

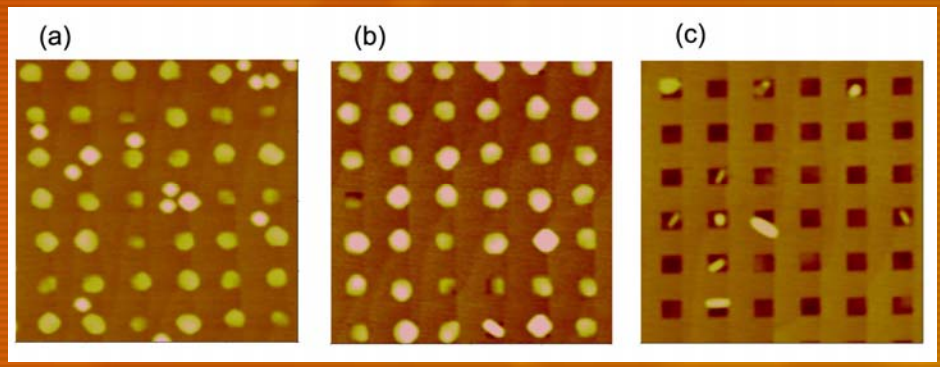
b) region

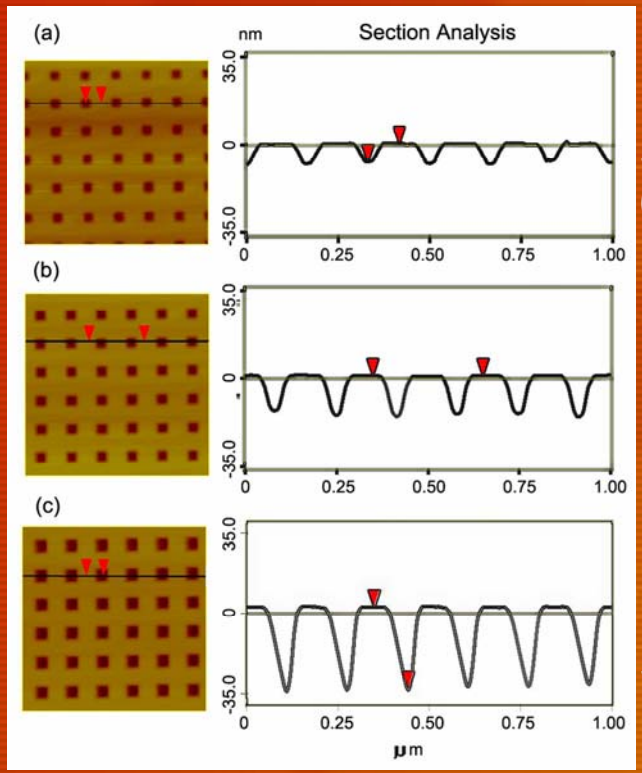
T = 700°C

Thickness: 7 Å

Patterned regions

- Comparison results
  - Varying FIB dose
  - Varying spacing





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- All FIB patterns affected island growth
- Extra islands in (a) while there are still unfilled holes in (c)
  - volume of pits vs. amount of Cu_2O.

Results:

Patterned regions

- Comparison results
  - Varying FIB dose
  - Varying spacing

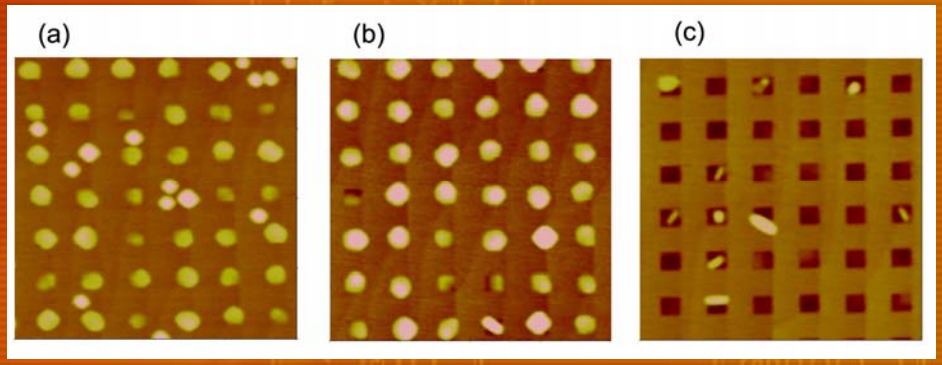
Process conditions:

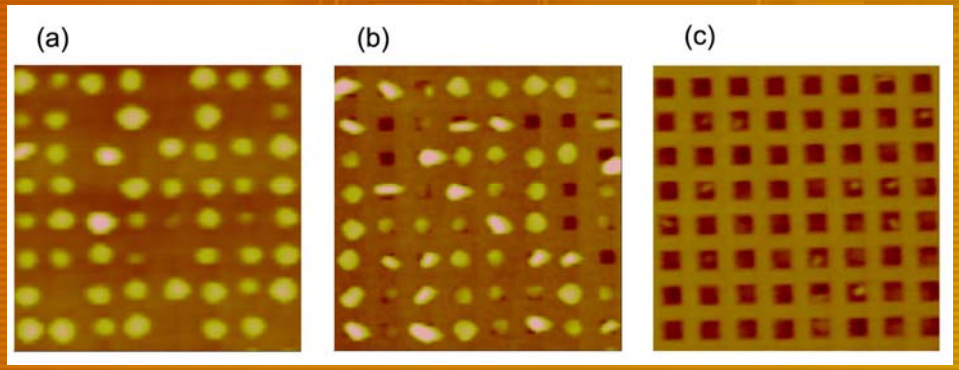
b) region

T = 700°C

Thickness: 7 Å

167 nm spacing





130 nm spacing

Results:

Patterned regions

- Comparison results
  - Varying FIB dose
  - Varying spacing

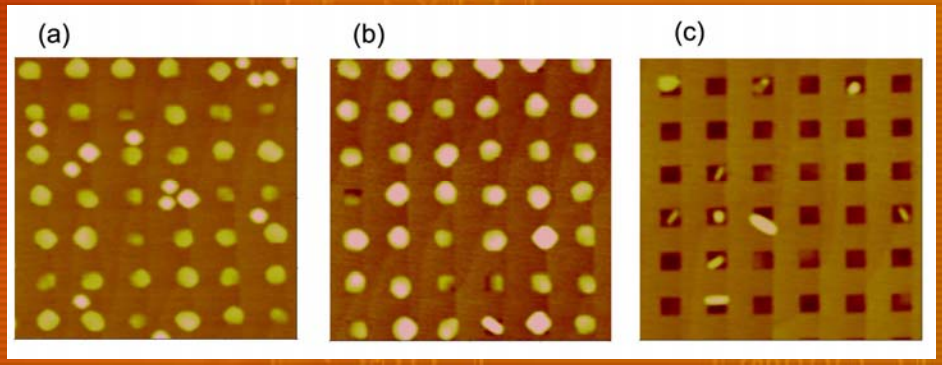
Process conditions:

b) region

T = 700°C

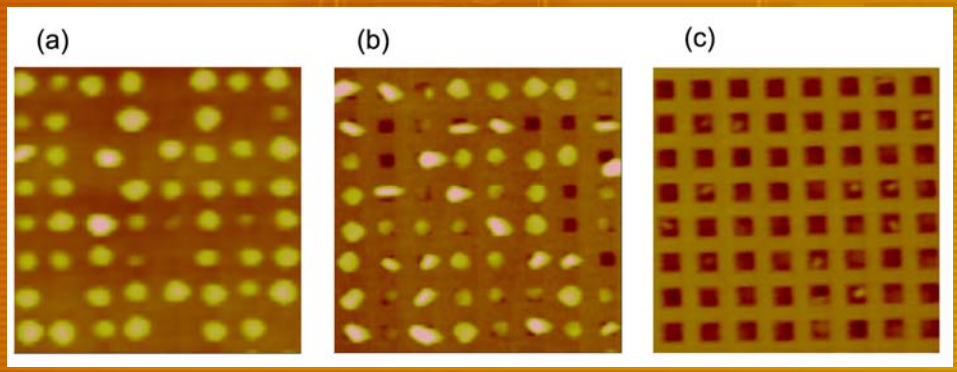
Thickness: 7 Å

167 nm spacing



Extra islands in 167 nm spacing pattern.

Unfilled FIB sites on 130 nm spacing pattern.



130 nm spacing

Results:

Patterned regions

- Comparison results
  - Varying FIB dose
  - Varying spacing

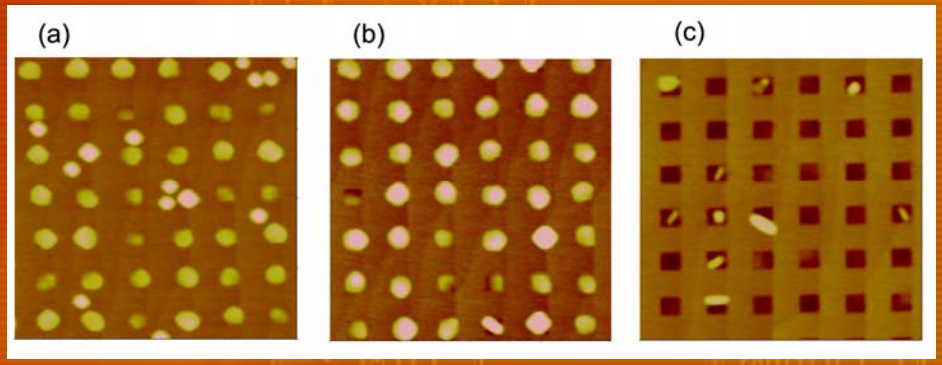
Process conditions:

b) region

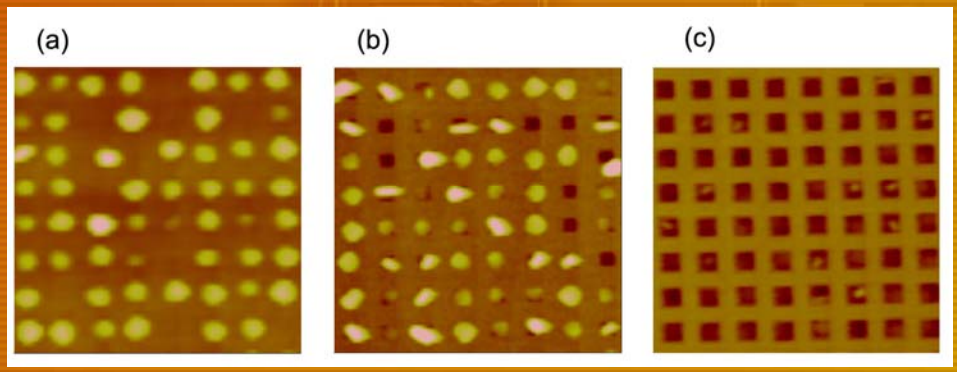
T = 700°C

Thickness: 7 Å

167 nm spacing



One to one in 167 nm spacing pattern. Unfilled FIB sites on 130 nm spacing pattern.



130 nm spacing

Results:

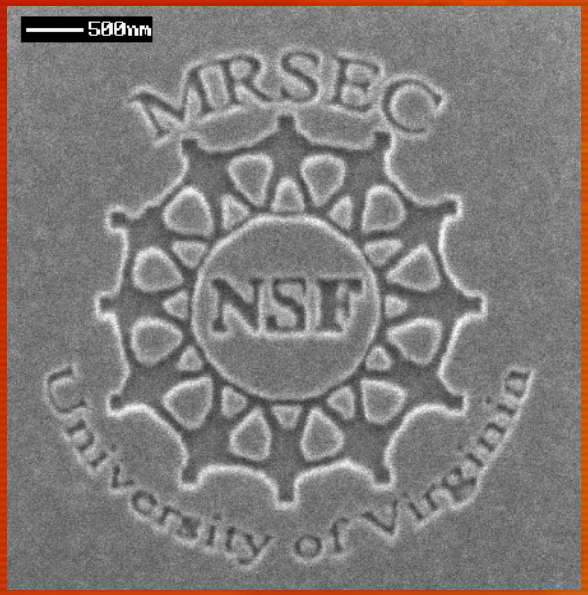
Patterned regions

- Comparison results
  - Varying FIB dose
  - Varying spacing
  - Varying thickness
  - Varying temperature ——— More details are discussed in the poster.

Discussions

- FIB patterning is a successful way to guide the growth of Cu_2O nanodots on $SrTiO_3$ (100) substrate.
  - Microscale 1:n; Nanoscale 1:1
  - Varying dosage to adjust the pit size
  - Varying thickness to fit different patterns
  - Varying patterns to fit certain density
- Possibility to extend this technique to other material systems
- Detailed growth mechanisms need to be further studied.
  - Ga^+ effect
  - Topography
  - Local stress/strain
  - Local chemistry

Acknowledgments:



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